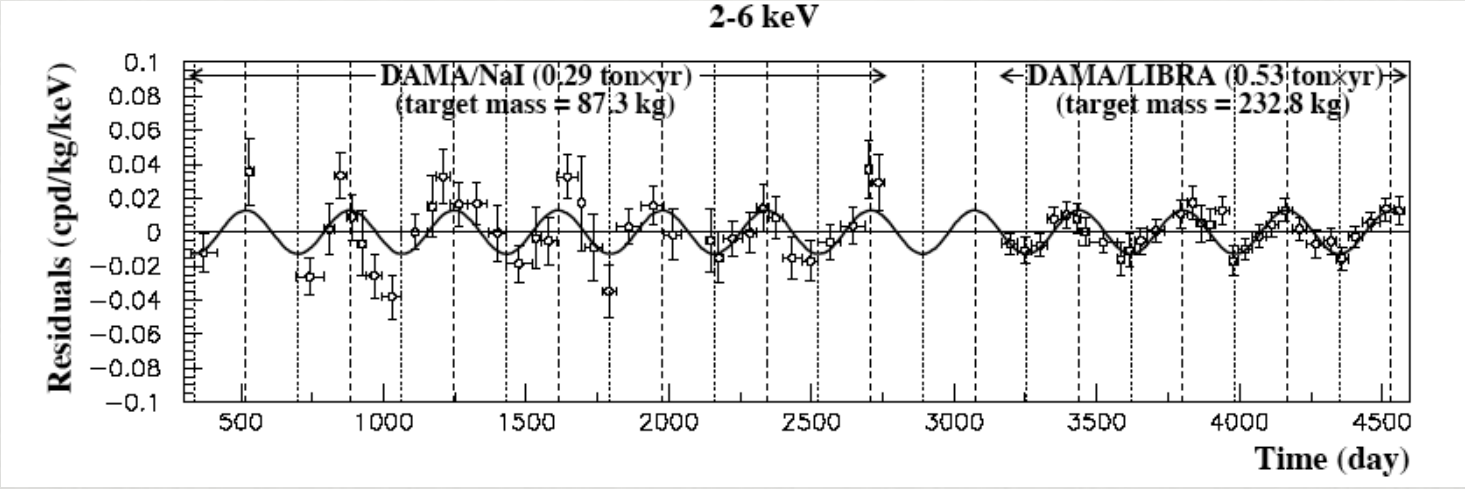
SABRE: A NaI dark matter experiment with active background rejection

Emily Shields
Frank Calaprice & Jingke Xu
Princeton University

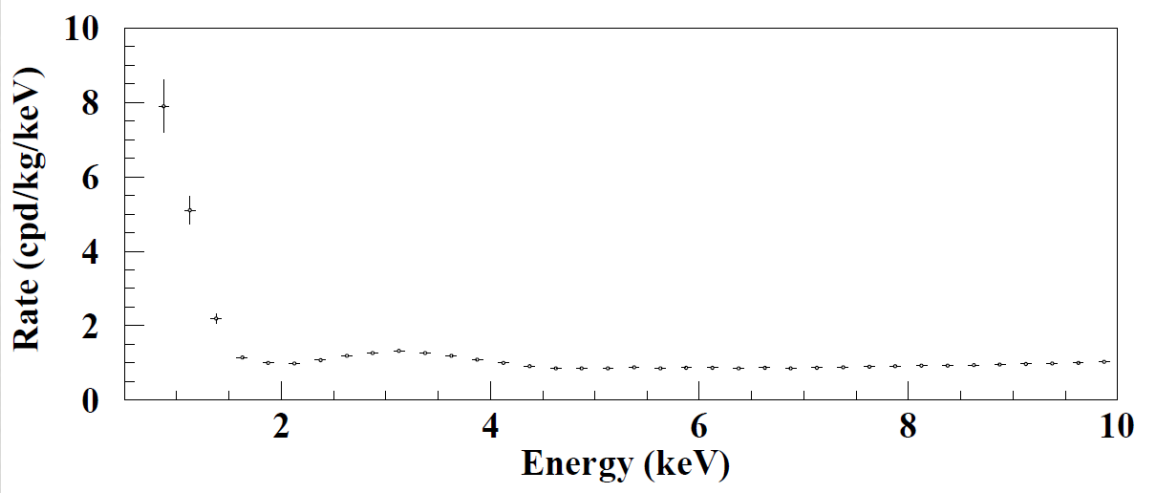
Introduction

- WIMP Dark Matter and the annual modulation
- The DAMA/LIBRA result
- Other experiments (CDMS, CoGeNT, XENON)
- Need for verification of the DAMA/LIBRA result

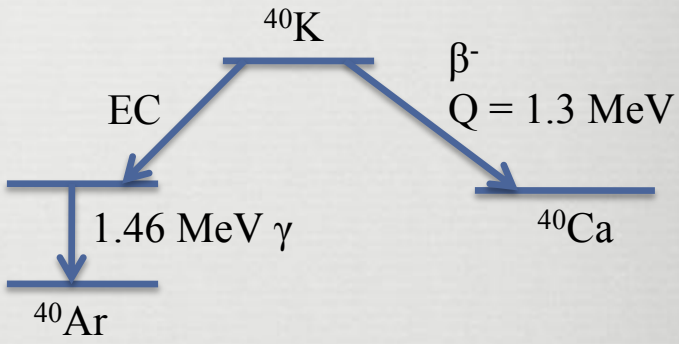


The Potential ^{40}K Background

- Trace amounts of K in NaI crystal (~13 ppb in DAMA*)
- 10.7% of ^{40}K undergoes e-capture decay to ^{40}Ar, which may produce a ~3 keV x-ray/Auger electron



DAMA/LIBRA energy spectrum

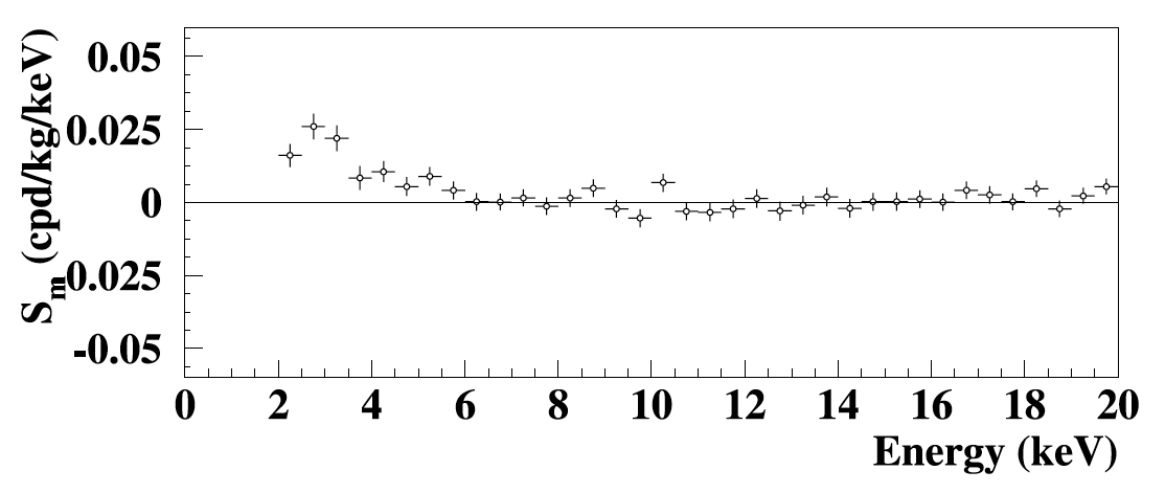


^{40}K Decay Scheme

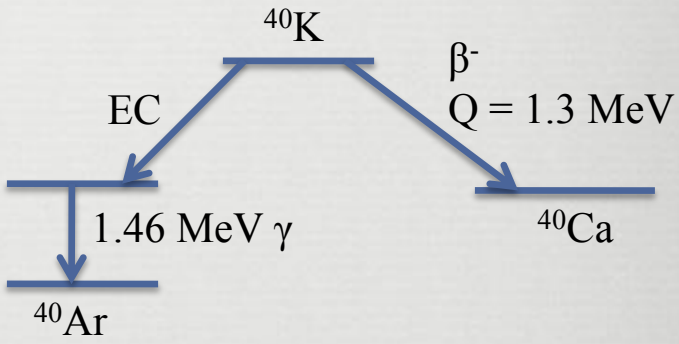
*R. Bernabei et al. (arXiv:1210.5501). 2012.

The Potential ^{40}K Background

- Trace amounts of K in NaI crystal (~13 ppb in DAMA*)
- 10.7% of ^{40}K undergoes e-capture decay to ^{40}Ar, which may produce a ~3 keV x-ray/Auger electron



DAMA/LIBRA modulation amplitude as a function of energy



^{40}K Decay Scheme

*R. Bernabei et al. (arXiv:1210.5501). 2012.

The Veto Concept

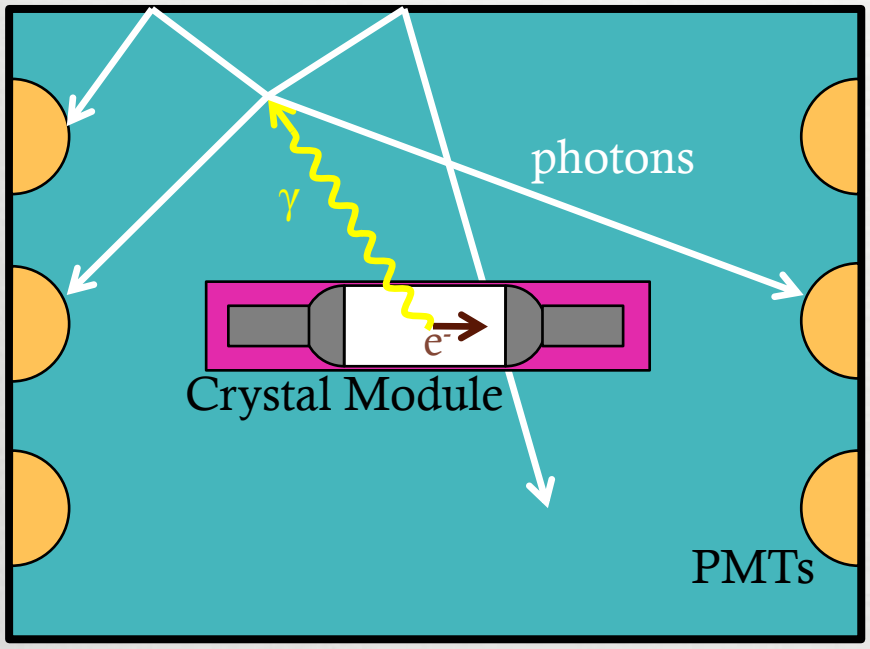
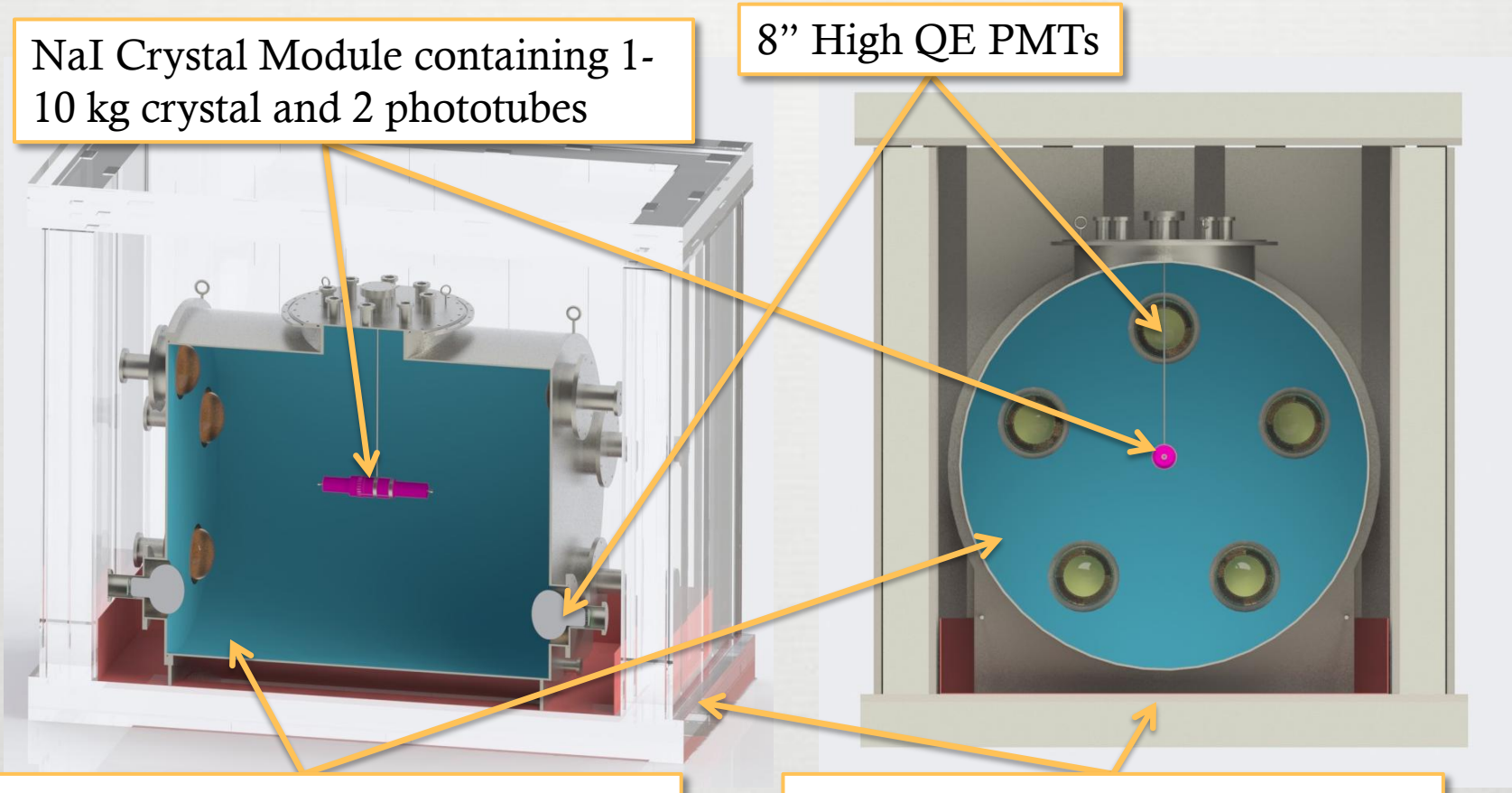


Illustration of veto principle (not to scale)

- Active background rejection
  - Backgrounds from crystal and surrounding components, especially ^{40}K decay in NaI
  - External backgrounds
- The veto detector
  - 1.5 m x 1.5 m cylinder
  - Liquid scintillator: linear alkyl-benzene (LAB)

SABRE (Sodium-iodide with Active Background REjection)



Experimental Plan

- Measurement of ^{40}K content in NaI
  - Create powder and grow crystals
  - Use the liquid scintillator detector as coincidence counter to measure K concentration in crystal
- Dark Matter Measurement
  - Liquid scintillator detector operates as veto for all background sources
  - Underground operation: potential sites include Gran Sasso and SNOLab

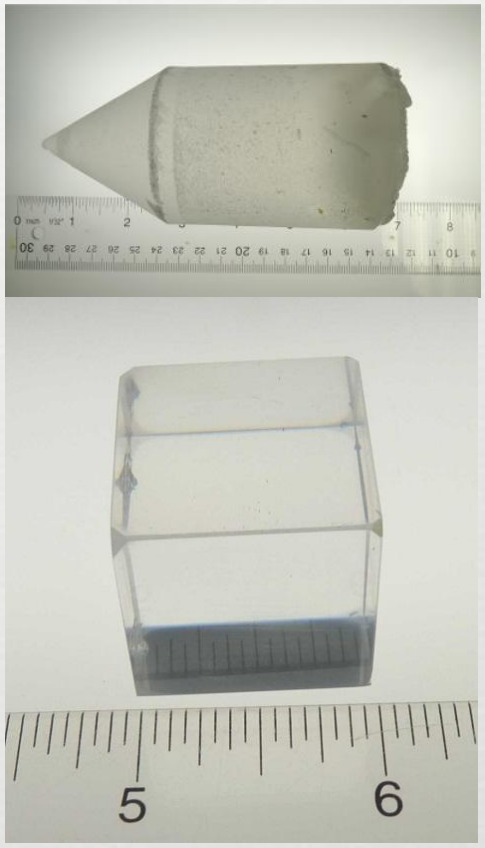
The NaI Powder

Powder	DAMA	MV Laboratories (Seastar)	Sigma Aldrich "Astro-Grade"
K	<100 ppb	12 ppb	3.5 ppb
Rb	0.5 ppb in crystal, powder unreported	14 ppb	0.2 ppb
Th	20 ppt	<200 ppt	<1700 ppt
U	20 ppt	<100 ppt	<500 ppt

- Have purchased 8 kg of powder from the two sources above
- Both have K concentrations lower than the final crystal concentration in DAMA of 13-20 ppb

Crystal Growth

- Working with RMD Inc. to grow the crystals
- Expect reduction of K in crystal growth process (4-5x)
- Have grown test crystals with vertical Bridgman method
- Future crystals to be grown in Pt Kyropoulos crucible
- Employ other purification methods to further reduce impurities



NaI ingot (top) and crystal (bottom) grown at RMD

Experiment Background

- Expected backgrounds
  - Crystal K, U, and Th
  - PMTs (in crystal detector and in liquid scintillator detector)
  - Crystal housing
  - Steel vessel for liquid scintillator and shielding
  - External background (room and cosmogenic)
- Two GEANT4 simulations of background for ^{40}K measurement and dark matter measurement

Background Estimate (^{40}K Measurement)

Background source	Expected activity	Expected background rate
Crystal (U&Th)	O(10) ppt	0.01 cpd/kg
Crystal PMTs	O(10) mBq/tube K,Th,U,Co (measured)	0.19 cpd/kg
Veto PMTs	O(10) mBq/tube K,Th,U,Co (measured)	0.06 cpd/kg
Steel and shielding	O(1-10) mBq/kg	0.2 cpd/kg
External (with 10^4 rejection from passive shielding)	O(1E-2) $\gamma/m^2/s$ (measured)	0.21 cpd/kg
Total		0.67 cpd/kg

Table of Backgrounds for ^{40}K Measurement (expected signal: 1 cpd/kg/10 ppb K)

Background Estimate (Dark Matter Measurement)

Background source	Expected/Measured activity	Expected background with veto	Veto rejection
Crystal K	10 ppb	0.05 cpd/keV/kg	91%
Crystal U & Th	10 ppt each	0.2 cpd/keV/kg	4%
Crystal PMTs	O(10 mBq/tube) K, Th, U, Co	1E-3 cpd/keV/kg/tube	83-98%
Veto PMTs	O(100 mBq/tube) K, Th, U	<5E-6 cpd/keV/kg/tube	>93%
Vessel	O(1-10 mBq/kg) K, Th, U, Co	<0.01 cpd/kg/keV	>93%
Shielding	O(1-10 mBq/kg) K, Th, U, Co	<0.06 cpd/kg/keV	>93%
External (SNOLab)	10,000 $\gamma/m^2/s$	<7E-3 cpd/kg/keV	78%
Total (1 crystal)		0.39 cpd/keV/kg	84%

Table of backgrounds: dark matter measurement (DAMA: 1 cpd/keV/kg)

Background Estimate (Dark Matter Measurement)

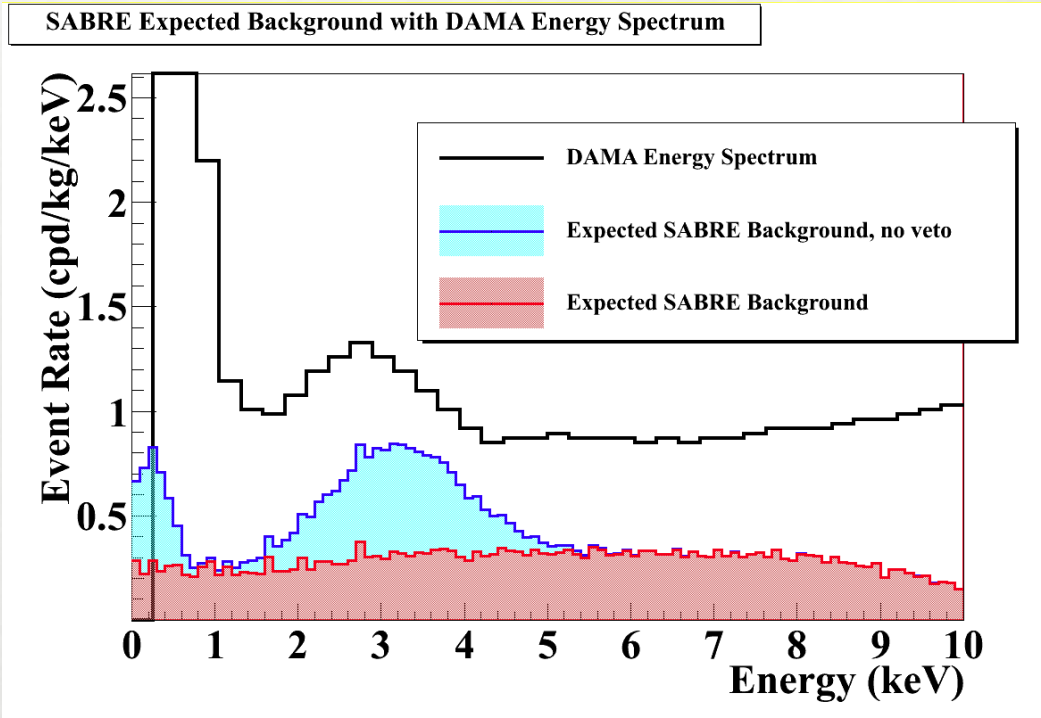
Background source	Expected activity	Expected background with veto	Veto rejection
Crystal K	10 ppb	0.05 cpd/keV/kg	91%
Crystal U & Th	10 ppt each	0.2 cpd/keV/kg	4%
Crystal PMTs	O(10 mBq/tube) K, Th, U, Co	1E-3 cpd/keV/kg/tube	83-98%
Veto P		<5E-6 cpd/keV/kg/tube	>93%
Vessel		<0.01 cpd/kg/keV	>93%
Shieldi		<0.06 cpd/kg/keV	>93%
External (SNOLab)	10,000 γ/m²/s	<7E-3 cpd/kg/keV	78%
Total (1 crystal)		0.39 cpd/keV/kg	84%

Background is ultimately limited by crystal impurities. Potassium background reduced 10x by veto.

Table of backgrounds: dark matter measurement (DAMA: 1 cpd/keV/kg)

Physics Implications

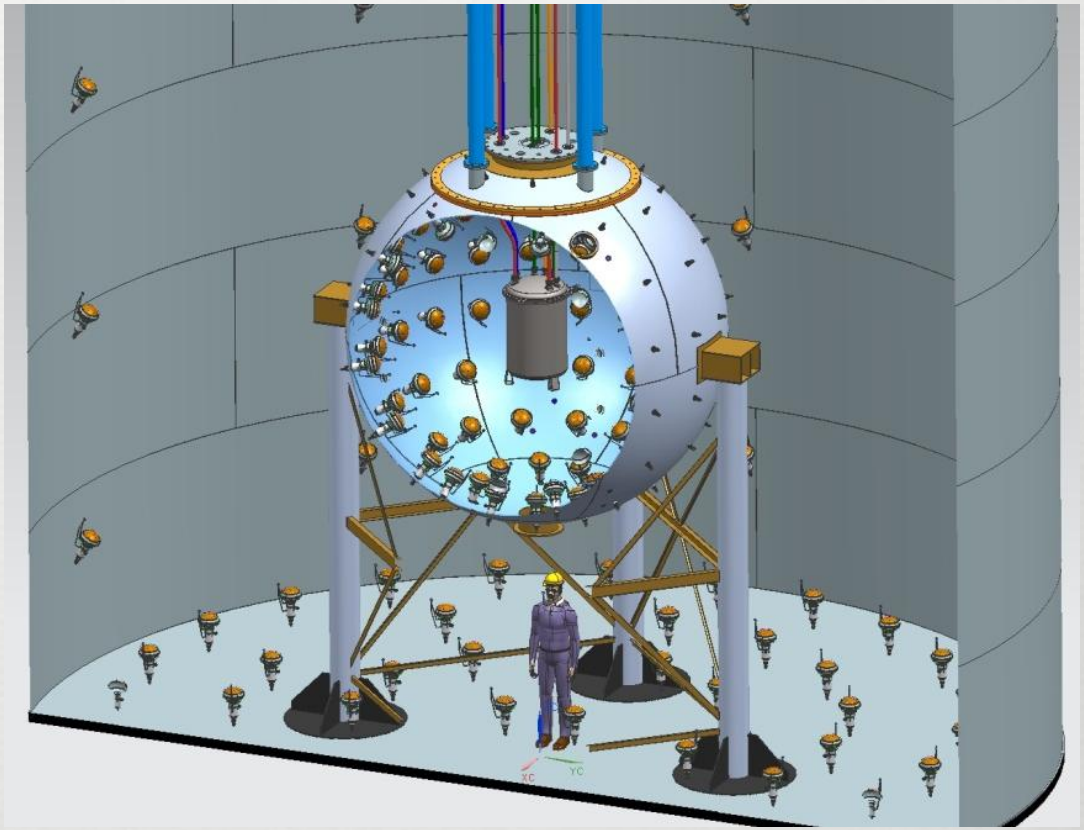
- SABRE is expected to reach a high sensitivity to modulation by rejecting a large portion of backgrounds.
- Even a few 10 kg crystals can reach a sensitivity to the DAMA/LIBRA observed mass/cross-section region in one year.



Comparison of DAMA spectrum with expected SABRE backgrounds for a 2 kg crystal

Future Plans

- Crystals can be placed inside the DarkSide-50 veto chamber
- We aim to house our veto chamber in Gran Sasso or SNOLab
- After the ^{40}K measurement phase, we aim to produce crystals for a 100-kg detector



DarkSide-50: Trunks entering veto chamber sized to fit our crystals

Conclusions

- SABRE will provide a direct test of the DAMA/LIBRA measurement
- SABRE is designed to improve upon DAMA/LIBRA with active rejection of backgrounds and possibly more radio-pure crystals
- Production of detector and crystals is underway
- We believe that with our current components we can achieve a background rate lower than DAMA